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Patent Application of

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for

Open Face Optical Fiber Array for Coupling to Integrated Optic Waveguides and Optoelectronic Submounts

RELATED APPLICATIONS

The present application claims the benefit of priority of copending provisional patent application 60/195,636, filed on 04/07/2000, which is hereby incorporated by reference.

FIELD OF THE INVENTION

The present invention relates generally to structures for coupling to integrated optical devices. More particularly, the present invention relates to an optical fiber array having an open top face for coupling to integrated optics (IO) chips that have V-grooves for receiving optical fibers. The arrays of the present invention allow many optical fibers to be aligned and bonded to an IO chip simultaneously.

BACKGROUND OF THE INVENTION

Integrated optics (IO) chips have waveguides that typically must be coupled to optical fibers. Coupling to optical fibers is difficult because the fibers must be accurately aligned with the waveguides.

In order to provide passive coupling alignment between opticalfibers and IO waveguides, IO chips may have V-grooves aligned colinearly with the waveguides. An optical fiber disposed in the V-groove is automatically aligned with the IO waveguide.

US Pat. 5,123,068 to Hakoun et al. discloses an IO chip having V-grooves for fiber alignment. In the device of Hakoun et al., the optical fibers must be placed in the V-grooves individually, a tedious task.

US Pats. 5,961,683 and 5,557,695 disclose IO chips having V-grooves in a substrate underlying the waveguides. Fibers placed in the V-grooves are aligned with the waveguides.

US Pat. 4,818,059 to Kakii et al. discloses an optical connector having a V-groove chip that is only partially covered by a lid. Exposed V-grooves facilitate the insertion of optical fibers into the V-grooves between the chip and lid.

Individual placement of optical fibers in fiber aligment grooves is time consuming and tedious. It would be an advance in the art to provide a structure and method for placing simultaneously a large number of fibers in fiber alignment grooves.

OBJECTS AND ADVANTAGES OF THE INVENTION

Accordingly, it is a primary object of the present invention to provide an open-face optical fiber array that:

1) can be mated with an integrated optics chips having fiber alignment grooves for accurately locating a large number of optical fiber simultaneously;

2) is simple to construct and can be used for a wide range of optical fiber pitches.

These and other objects and advantages will be apparent upon reading the following description and accompanying drawings.

SUMMARY OF THE INVENTION

These objects and advantages are attained by an optical fiber array having a V-groove chip with V-grooves and an optical fiber disposed in a V-groove. The V-groove chip has a rear portion and a front portion. The front portion has a front face. The optical fiber is bonded (e.g. glued, soldered, or thermo-compression bonded) to the rear portion; the optical fiber is not bonded to the front portion. Preferably, the optical fiber endface is flush with a front face of the V-groove chip.

The array can also have micromachined pits for receiving alignment spheres (e.g. alignment spheres).

A wick stop trench can be disposed between the rear portion and the front portion to control the flow of adhesive (e.g. (glue or solder).

The present invention also includes an embodiment where the chip has a rear portion, a middle portion and a bonded front portion. The optical fibers are bonded to the chip in the rear portion and the bonded front portion; the optical fibers are not bonded to the middle portion. In this embodiment, the middle portion mates with the V-grooves of an IO chip.

Sub a3 The present invention also includes a method for bonding optical fibers to an optical device (e.g. IO chip or optoelectronic submount)

DESCRIPTION OF THE FIGURES

Fig. **1** shows a perspective view of the open face fiber array of the present invention.

Fig. **2** shows a second perspective view of the fibr array where the fiber array has a lid.

Fig. **3** shows an integrated optics chip structure that can be coupled to the present optical fiber array.

Fig. **4** shows a perspective view of the fiber array and an IO chip illustrating how the fiber array and IO chip are coupled.

Fig. **5** shows a side view of the fiber array and IO chip coupled.

Fig. **6** shows a perspective view of an optoelectronic submount that can be coupled to the present fiber array.

Fig. **7** shows an IO chip having a smooth surface for contact with the optical fibers.

Figs. **8a-8e** illustrate a method for making the optical fiber array of the present invention.

Fig. **8f** shows an alternative embodiment of the present invention where the array has an angled front face. The front face is angled forward so that it overhangs the IO waveguide structure.

Fig. **9** shows an alternative embodiment having alignment spheres for providing alignment between the array and IO chip.

Fig. **10** shows an alternative embodiment where the pits for the alignment spheres are large enough to allow active positioning of the fiber array.

Fig. **11** shows an alternative embodiment of the present invention where the optical fiber is bonded to the rear portion and a bonded front portion; the optical fiber is not bonded in a middle portion of the array.

Fig. **12** shows how the array of **Fig. 11** is mated with an IO chip.

Fig. **13** shows a cross sectional view of the front portion where the V-groove in the front portion is large so that

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is does not fully define the location of the optical fiber.

DETAILED DESCRIPTION

The present invention provides an open-face optical fiber array for coupling to substrates (e.g. integrated optics (IO) chips) having optical fiber alignment grooves. The open-face array has a V-groove chip with optical fibers disposed in the V-grooves. The V-groove chip has a rear portion where the fibers are bonded in the V-grooves (e.g. with glue), and a front portion where the optical fibers are NOT bonded to the V-grooves. The front portion has a front face that is preferably polished. The optical fibers extend from the rear portion. The optical fibers have endfaces that are preferably flush with the front face. A lid may be disposed on top of the rear portion where the optical fibers are bonded. In use, the array of the present invention is mated with an IO chip so that the unbonded optical fibers are pressed into the V-grooves of the IO chip. Since there is no glue on the optical fibers in the unbonded front portion, the fibers can be accurately aligned in the IO chip V-grooves

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Fig. 1 shows a perspective view of an open face optical fiber array according to the present invention. The open face fiber array has optical fibers **20** disposed in precision V-grooves **22** of a V-groove chip **23**. For clarity, one V-groove in the array does not have a fiber. The array has a rear portion **24** and a front portion **26**. The front and rear portions may be the same or different lengths (in the direction of the V-grooves). In the rear portion **24**, the optical fibers are bonded to the V-groove chip **23**; in the front portion **26**, the optical fibers are necessarily NOT bonded to the V-groove chip **23**. In the present speification, the rear portion **24** is defined as a

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region where the fibers are bonded to the chip **23**. The front portion is defined as a region where the optical fibers are not bonded to the chip **23**. Preferably, the optical fibers **20** are bonded to the rear portion **24** with glue **28**. Optionally, the optical fibers can be bonded to the rear portion **24** with solder or other materials or by using other techniques (e.g. thermo-compression bonding).

In a preferred embodiment of the invention where glue is used to bond the optical fibers **20**, a wick stop trench **30** is provided. The wick stop trench **30** separates the rear portion **24** and the front portion **26**. The wick stop trench serves to prevent the flow of liquid glue by capillary action to the front portion **26**. The wick stop trench is described in copending patent application **09/526,922**, which is hereby incorporated by reference. The wick stop trench is optional, but preferred, in embodiments where flowable glues (e.g. UV- or heat-curable epoxy) or liquid solders are used to bond the optical fibers to the chip **23**.

If a wick stop trench is not used, then highly viscous glues with low capillary flow can be used to bond the optical fibers to the chip. Viscous glues tend to not flow to the front portion **26** from the rear portion **24**.

In an alternative embodiment of the present invention, thermo-compression bonding is used to bond the optical fibers to the rear portion. For example, US pats 5,389,193 and 5,178,319 disclose useful methods of aluminum thermo-compression bonding for bonding optical fibers to V-grooves. In the case where aluminum thermo-compression is used, it is preferable to only deposit aluminum in the rear portion of the V-groove chip. In this way, the optical fiber is only bonded to the rear portion.

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Fig. 2 shows another perspective view of the open face fiber array. The array in **Fig. 2** has an optional lid **32** covering the rear portion **24**. The lid **32** is preferably glued to the optical fibers and chip **23**. The array has a front face **34** at the edge of the front portion **26**. The optical fibers **20** have fiber endfaces **36**. The endfaces can be cleaved or polished; preferably, the endfaces **36** are polished. Also preferably, the fiber endfaces **36** are flush with the front face **34**. In a particually preferred embodiment, the front face **34** and fiber endfaces **36** are polished in the same polishing step. This assures that the fibr endfaces **36** and the front face **34** are flush.

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Fig. 3 shows a perspective view of an integrated optics chip structure that can be coupled to the optical fiber arrays of the present invention. The integrated optics (IO) chip has waveguides **38** disposed in a cladding material **40**. The waveguides and cladding are disposed on a substrate chip **42** (e.g. made of silicon). The waveguides **38** and cladding can be made of silicon, polymer materials or silica. V-grooves **44** for aligning optical fibers are disposed in alignment with the waveguides **38**. The waveguides **38** intersect a sidewall **46** that is smooth enough for optical coupling to the waveguides. The V-grooves **44** and waveguides **38** are separated by a cut groove **48**. The cut groove may be a dicing saw cut groove, for example. The use of a dicing saw cut groove in IO chips is known in the art.

The cut groove **48** preferably has a width less than 5-6 times the diameter of the optical fiber so that bending of the optical fiber in the region of the cut groove is minimized. For example, for 125 micron diameter optical fibers, the cut groove **48** should have a width less than about 700 microns.

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More preferably, the cut groove has a width less than about 300 or 150 microns.

It is noted that the present optical fiber arrays can be used to couple to IO chips that do not have cladding material **40** disposed on the waveguides. For example, the waveguides can be made of polymer material disposed directly on the substrate chip or a cladding layer.

Fig. 4 illustrates how the optical fiber arrays of the present invention mate with the IO chip shown in **Fig. 3**. In the present invention, the optical fibers **20** in the array are pressed into the V-grooves **44** of the IO chip. Since the optical fibers **20** are not bonded to the front portion **26**, the fibers can shift slightly to fit perfectly within the IO chip v-grooves **44**. It is important to note that only the front portion **26** is mated with the IO chip. Also, since the fibers are not bonded in the front portion **26**, there is no danger of residual, hardened glue interfering with contact between the fibers **20** and the IO chip V-grooves **44**. This is an important consideration because even a very thin film (e.g 1-3 microns) of glue residue on top of the fibers **20** can significantly harm fiber-waveguide alignment.

After the optical fibers **20** are disposed in the V-grooves **44**, glue or solder is applied to bond the fibers to the IO chip. Preferably, the optical fiber endfaces **36** are butted against the waveguides **38**. The interface between the optical fibers and the waveguides can be oriented at a nonperpendicular angle with respect to the optical fibers and waveguides to reduce backreflections. In this case, the front face **34** and the cut groove **48** should be cut at precisely matching angles.

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Fig. 5 shows a side view of the present fiber array coupled to an IO chip.

The fiber arrays are also useful for coupling optical fibers to optoelectronic submounts. The optoelectronic submount can have a laser array or photodetector array disposed adjacent to V-grooves. **Fig. 6** shows an exemplary optoelectronic submount that can be coupled to the present fiber array. The submount has a submount chip **52** with pedestals **54** for alignment of an optoelectronic chip **56**. The submount chip also has V-grooves **58** for positioning optical fibers. The submount chip may also have a cut groove analogous to cut groove **48** in the IO chip of **Fig. 3**. However, it is generally preferable for the submount chip to not have a cut groove (i.e., analogous to cut groove **48**). This is because a cut groove can contribute to fiber misalignment. It is also noted that an IO chip can be substituted for the optoelectronic chip **56**.

Fig. 7 shows an alternative embodiment where the IO chip does not have V-grooves **44**. Instead, surface **60** is smooth. The fiber array of the present invention can be coupled to this structure by pressing the optical fibers against the smooth surface **60**. After the fibers are actively aligned, the optical fibers are bonded to the smooth surface **60** using glue or solder.

Figs. 8a-8e illustrate a method for making the optical fiber array of the present invention. The steps for making the fiber array are as follows:

Fig. 8a: Optical fibers are disposed in the v-grooves of the V-groove chip.

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Fig. 8b: A lid **32** is placed on top of the optical fibers on the rear portion **24**. Glue is applied to the rear portion to adhere the lid **32**, fibers and v-groove chip.

Fig. 8c: A temporary holding plate **66** is pressed against the front portion **26**. The plate is not glued to the fibers. The plate **66** may be pressed against the fibers using a metal spring or clamp. The plate **66** may have V-grooves or may be flat.

Fig. 8d: The front portion and optical fiber **20** (and, optionally the plate **66**) are lapped and polished to plane **68**. The plane **68** can be perpendicular to the optical fibers, or set at an angle to the optical fibers. Plane **68** may be set at an angle in order to reduce backreflections. This is particularly useful in applications where the cut groove **48** in the IO chip is cut at an angle. In this case, angles of the plane **68** and cut groove **48** should match.

Fig. 8e: The plate 66 is removed. Optical fibers are not bonded to the V-groove chip in the front portion **26**. The optical fibers have polished endfaces 36 that are accurately flush with the front face 34 of the V-groove chip.

Alternatively, the lid **32** is removed after the fibers are glued. The lid **32** can have a nonstick (e.g. PTFE) coating to prevent glue from bonding the lid **32** to the array.

Fig. 8f shows a side view of an array with an angled front face **51** mated with an IO chip. In this specific embodiment, the front face **51** is angled forward so that it overhangs the waveguide **38**. This is preferable because the angled waveguide **38** tends to push the optical fiber into the V-groove **22**. The fiber array and waveguide can be angled at about 5-20 degrees,

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for example, to reduce backreflections. It is noted that the fiber array and waveguide can be angled 'backward' as well, so that the waveguide 'overhangs' the optical fiber **20**.

Fig. 9 shows an embodiment where the optical fiber array has pits **70** for receiving alignment spheres **72** (e.g. ball lenses) that mate with pits **74** on the integrated optics chip. The optical fibers **20** are in contact with the smooth surface **60**. Alternatively, the pits **70 74** are used in combination with V-grooves **44** in the IO chip.

Fig. 10 shows another embodiment where the pits **70** are made wider than the alignment spheres **72** so that the optical fiber array can move slightly on the smooth surface **60** (alternatively, pits **74** are made wider than the alignment spheres). Of course, this feature is only applicable if the IO chip has the smooth surface **60**. By allowing the optical fiber array to move slightly, both active and passive alignment can be provided; passive alignment is provided by mating the pits and alignment spheres, and active alignment is allowed because the alignment spheres can move slightly (e.g. 10-20 microns) within the pits.

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Fig. 11 shows another aspect of the present invention where the array has a second wick stop trench **80**. The first wick stop trench **30** and second wick stop trench **80** divide the fiber array into three parts: the rear portion **24**, a middle portion **82**, and a bonded front portion **84**. The fibers **20** are bonded to the rear portion **24** and the bonded front portion **84**. The fibers are not bonded to the middle portion **82**. Preferably, the fibers are in close contact with the V-grooves in the middle portion; the fibers must not be buckled or bent in the middle portion **82**. Also, it is noted that the bonded front portion **84** is relatively short (preferably less than 1 mm

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long). The bonded front portion **84** must be shorter than the width of the cut groove **48** in the IO chip.

The embodiment of **Fig. 11** solves a potential problem with the array of **Figs. 1** and **2**. In the arrays of **Figs. 1** and **2**, the optical fiber can bend slightly in the area of the cut groove **48** thereby causing misalignment between the optical fiber and IO wavgeuide **38**. The fiber can bend slightly in the area of the cut groove **48** because the fiber is not bonded to the V-groove **22**.

By comparison, the optical fiber **20** cannot bend in the area of the cut groove **48** when the array of **Fig. 11** is used. This is because the optical fiber **20** is glued to the bonded front portion **84**.

Fig. 12 shows a side view of the array of **Fig. 11** mated with an IO chip. The bonded front portion **84** is shorter than the cut groove **48**. Since the optical fibers are bonded to the bonded front portion **84**, the fibers cannot become misaligned. Also, the optical fibers are not bonded to the middle portion **82** until after the array is mated with the IO chip. This allows the fibers to seat properly in the V-grooves **44** of the IO chip.

In one embodiment, the V-grooves **22** are wider in the front portion **26** than the rear portion **24**. In this embodiment, the position of the optical fibers **20** is not fully determined by the V-grooves in the front portion **26**. This is advantageous in some applications because it allows the IO chip V-grooves **44** (or, equivalently, the submount chip V-grooves **58**) to determined the positions of the optical fibers **20**. **Fig. 13**, for example, shows a cross sectional view of an optical fiber disposed in a V-groove **90** that does not fully determine the

position of the the optical fiber. The fiber can move left-right in the V-groove **90** because the optical fiber only contacts a flat bottom surface **92**. It is noted, however, that the V-groove chip must be able to press the optical fiber into the V-groove **44** of the IO chip. For example, the V-groove **90** has the flat bottom surface **92** that can press the optical fiber into the IO chip V-groove **44**.

It is noted that if the fiber array is mated with an IO chip (or submount) having a smooth surface **60** (shown in **Fig. 7**), then the V-grooves **22** in the front portion **26** must fully define the optical fiber position.

Preferably, the position of the optical fiber in the rear portion is fully defined by the V-grooves, but this is optional.

In the present invention, the V-groove chip is preferably made from silicon using anisotropic etching techniques. Other materials can also be used for the V-groove chip such as glass, ceramics or plastics. In these cases, the V-grooves can be cut using a diamond saw, or the V-groove chips can be molded. The wick stop trenches can be anywhere from 50 microns to 1000 microns wide. The best width for the wick stop trenches depends upon the capillary flow characteristics of the glues or solders used. Also, the wick stop trenches should be deeper than the V-grooves.

It will be clear to one skilled in the art that the above embodiment may be altered in many ways without departing from the scope of the invention. Accordingly, the scope of the invention should be determined by the following claims and their legal equivalents.